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د.أ عامر

University of Tripoli

Faculty of Engineering

Electrical and Electronic Engineering

Course Number: EE362 **Course Name:** Control Systems

Credit Hours: 3 **Prerequisite:** Signals and systems

Lecture time:

Group (A) Sunday – Wednesday (9:30-10:45) **Classroom 6**

Group (B) Sunday – Wednesday (11:00-12:15) **Classroom 6**

Text Book:

Norman S. Nise, "Control Systems Engineering", 6th ed., John Wiley and Sons (Asia), 2008.

References:

"Modern Control Engineering" by K. Ogata, Prentice Hall, 4th Edition, 2002.

"Modern Control of Systems" by R. C. Dorf, R. H. Bishop, Prentice Hall, 9th Edition, 2002.

"Automatic Control Systems" Golnaraghi & Kuo, Wiley, 9e, 2010.

Computer resources: MATLAB & SIMULINK

MATLAB has become an industry standard and an essential tool for the modern engineer. It is assumed that you are familiar with the basics of MATLAB. Various aspects of MATLAB use and programming will be required in laboratories, but are also useful for problem solving and any project work. Further, familiarity with MATLAB can be a great help in learning control as it allows one to quickly set up examples and test ideas. A useful website on control tutorials for MATLAB is:

http://www.engin.umich.edu/group/ctm/

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A CD containing Matlab may be borrowed from (instructor course). For those students who do not have their own computers, access to these programs is available in the undergraduate computer laboratory.

Control Systems Laboratory

Lab. time: Wednesday (14:30-16:30) **Lab. Location:** Computer Lab

Objectives

- Learn to simulate dynamic systems in the Matlab environment.
- Familiarize the student with theoretical and practical aspects of making physical Measurements.
- Familiarize students with the behavior of control systems and enable them to understand the role the system parameters in control system response.
- Develop skills in writing technical reports.

Course Description

This course introduces the basic concepts of control systems, and covers real-world problems and applications of control systems as examples and case studies. This course is to explore the modeling of linear system via differential equations and transfer functions utilizing state space and input – output representations; analysis of control system in the time and frequency domains and using transfer function and state-space methods , study of the classical stability tests , such as the Routh- Hurwitz and Nyquist criterions, and design methods using root-locus plots and Bode plots.

Syllabus

1- Introduction to control systems, feedback control.

2- Systems Modeling: Laplace Transforms, Differential Equations.

3- Systems Modeling: Block Diagrams Mathematical Models

4- Systems Modeling: Transfer functions, State space models, Signal Flow Graphs.

5- Time Domain Analysis: Responses of 1 and 2 order systems, Time Response Specifications.

6- Stability Analysis: Routh-Hurwitz stability.

7- System Performance: Steady State Errors.

8- Root Locus Technique .

9- Design via Root Locus.

10- Frequency Domain Analysis: Bode Plots.

11- Frequency Domain Analysis: Nyquist Criterion.

12- Design via Frequency Response.

13- Design via state space.

14- Applications.

Assessment Scheme

There are totally 10 homework's, 8 quiz's, 1 project, (Midterm exam), Lab reports and final exam for this course.

Grading

Quiz's	Homework's	Lab reports	Term Project (MATLAB)	Midterm Exams	Final Exam
5%	5%	5%	5%	30%	50%

Notes:

1- The lecture notes are printed and they are available in the square office.

2- Lectures start in Week 1. *Lab start in Week3 * Tutorials start in Week 3.

3- Homework will be done in one week from the day it is assigned.

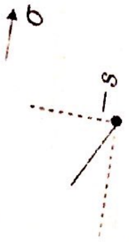
4- If you can solve homework problems well, you will do great in the exam.

5- Late homework will not be accepted unless you prove (with some documents) that your case is legitimate.

6- If all problems are solved (not necessarily correct), 50% of the credit will be given. If only some of problems are solved, this 50% of the credit will be prorated.

7- Each homework, randomly chosen a subset of problems will be graded carefully, which will make up for the other 50% of the credit.

8- No work will be accepted if placed in my mailbox.



9- Use only staples to attach multiple pages

10- Tardiness is not allowed.

11- 8.5 x 11 inch paper is required and with perforated edges.

12 - It is the student's responsibility to remember the due date.

13- All reports of the lab must be processed with a computer.

14- No work will be accepted after the last day of classes.

15- Students must demonstrate and present a successful, working final project.

16 - In the exam, you are allowed to bring a letter sized paper (one side) where you can write important formulas and equations. It has to be only with your hand-written formulas.

17- If you want to get a very good grade: ***Read the textbook thoroughly. Read optional references too.*** ***Do more than given Exercises.*** ***Use and be familiar with Matlab.***

Course objective

The objective of this course is to enable students to model, analyze and control engineering systems. So, given a system (a robot, an elevator, a disk drive), you will be able to model the behavior, perform an analysis, and then design controller so that the system behaves in a certain prescribed way.

Students completing EE362 should:

- Understand continuous control theory for analysis and design of control systems.
- Understand system performance and the influence of control architecture, parameter values, process dynamics.
- Understand use and utility of computer tools for control analysis and design.

Week #1

Basic Control System Concepts EE362

System: Any organized assembly of resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions.

Control System

A control system consists of subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input.

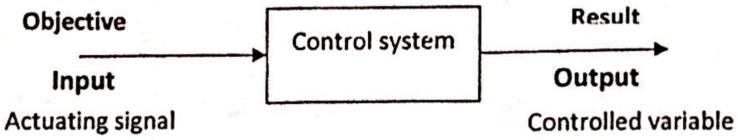
Control Engineering

Control engineering is concerned with the analysis, design and implementation of goal-oriented systems.

Basic Components of a Control System

The basic ingredients of a control system can be described by:

1. Objectives of control.
2. Control-system components.
3. Results or outputs.



Type of control

- **Regulator**

– Maintains constant output despite disturbances ***(e.g. automobile cruise control, room temperature)***.

- **Compensator**

– Drive system from an initial to a final state according to specifications on the transient response ***(e.g. elevator)***.

- **Tracking**

– Match output to a non-stationary input despite disturbances. Make system variables follow continually changing desired values ***(robot motion, missile guidance)***.

- **Optimal control**

– Drive system from an initial to a final state while optimizing a merit function (minimum time to target or minimum energy consumption), (***e.g. hard disk drive)***.

Control and System Engineering Problems

In general, a control and system engineering problem can be divided into the following steps:

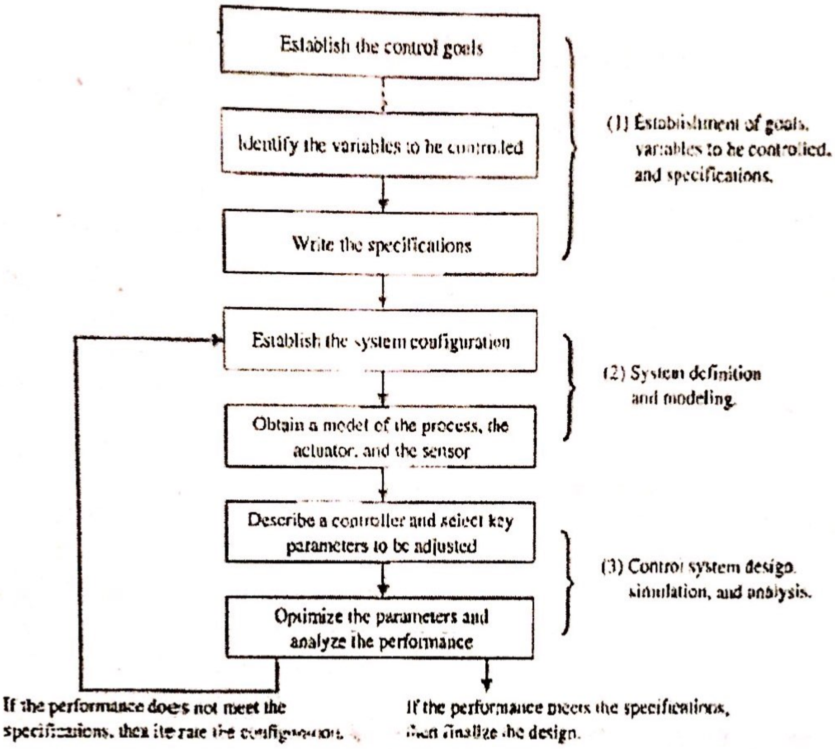
1. Established a set of performance specifications.

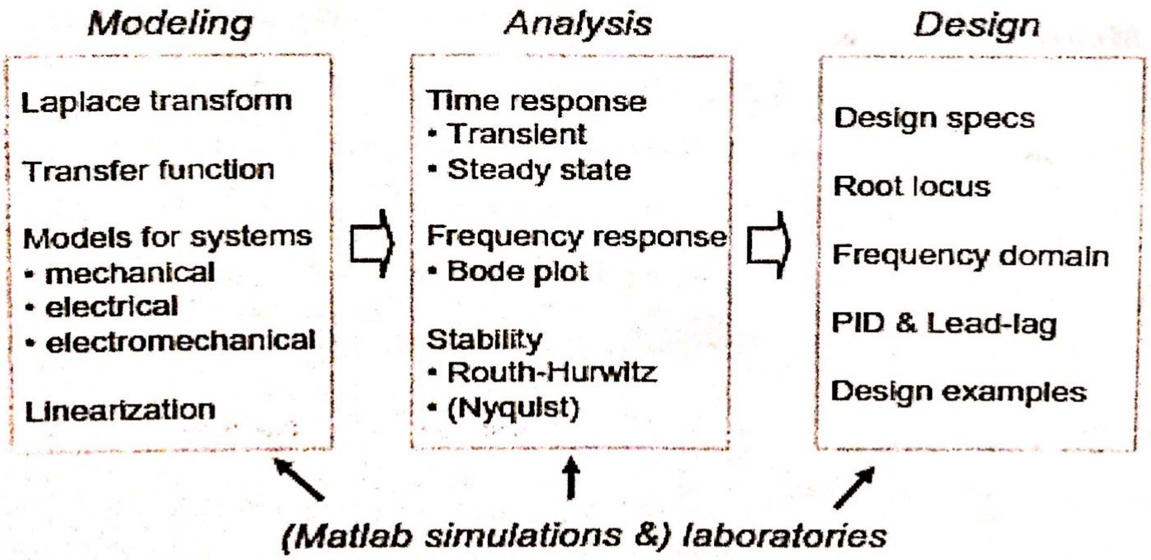
2. Formulate/Derive a set of differential equations describing the behavior of the physical system.

3. Analyze the performance of the original system (many methods can be used)

4. Design and add control element to improve the response if the performance does not meet the specifications.

5. System optimization may be required.


Establish the control goals
Identify the variables to be controlled
Write the specifications
(1) Establishment of goals, variables to be controlled, and specifications.
Establish the system configuration
Obtain a model of the process, the actuator, and the sensor
(2) System definition and modeling.
Describe a controller and select key parameters to be adjusted
Optimize the parameters and analyze the performance
(3) Control system design, simulation, and analysis.
If the performance does not meet the specifications, then iterate the configuration.
If the performance meets the specifications, then finalize the design.


Modeling
Laplace transform
Transfer function
Models for systems
• mechanical
• electrical
• electromechanical
Linearization
Analysis
Time response
• Transient
• Steady state
Frequency response
• Bode plot
Stability
• Routh-Hurwitz
• (Nyquist)
Design
Design specs
Root locus
Frequency domain
PID & Lead-lag
Design examples
(Matlab simulations &) laboratories

Control system design

System Modeling

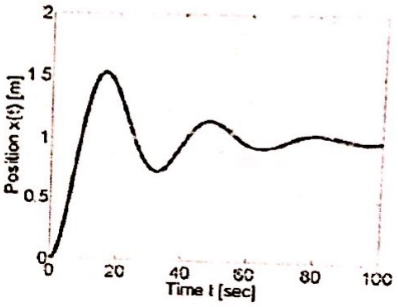
$$m\ddot{x}(t) + b\dot{x}(t) + kx(t) = F(t)$$

Hardware

Model (ODE)

System Dynamics

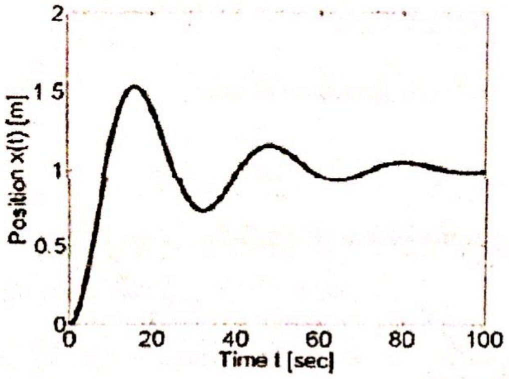
$$m\ddot{x}(t) + b\dot{x}(t) + kx(t) = F(t)$$

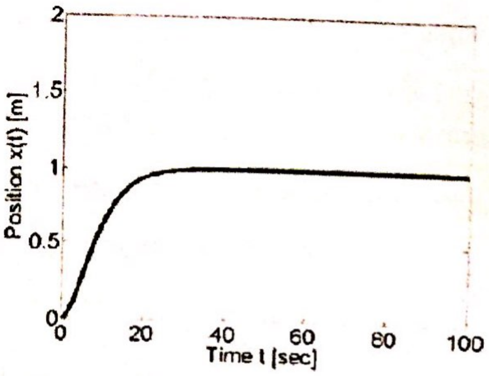


Model

Response

System Control





Response

Desired Response

Performance Specifications

Let's take the example of an elevator. You want the following to happen:

1. Get to your destination (desired floor) as fast as possible. However, you want a smooth ride so that you don't get sick in the elevator.

2. You don't want the elevator to be bouncing up and down before it settles to the desired floor. For example, if your upward destination is the 4th floor, you don't want the elevator to go to the 5th floor first then comes back to the 4th floor (i.e. no overshoot).

3. You want the elevator to stop at about the same level as the floor, otherwise you might trip and fall (i.e. you can only tolerate a very small steady state error).

4. You want the speed of the elevator to be the about the same regardless of the load. That is, you want the elevator to take about the same time to travel from the 1st floor to the 10th floor, whether you have 1 or 10 passengers in the elevator.

All these requirements are called **performance specifications**. A control engineer will have to ensure that their control systems meet the desired specifications, by implementing controllers to change the systems' behaviour, if necessary.

Controller

The controller is the component (or group of components) that controls the process.

- The controller outputs are the variables that manipulate the process.
- The controller inputs include the desired values of the process output variables, and may also include the actual values of the process variables (feedback).
- The objective of the controller is to make the actual values of the process output variables equal to the desired values.

Automatic Control

Control is automatic if it is accomplished without manual (human) intervention.

Why study automatic controls?

- Automatic control of industrial processes (chemical, paper, automotive, etc.) is called automation. Automation enables:
  - Less expensive products.
  - More reliable and higher quality products.
  - Quick adaptation to changes in markets.

Classification of Control Systems

Control systems are basically classified as -

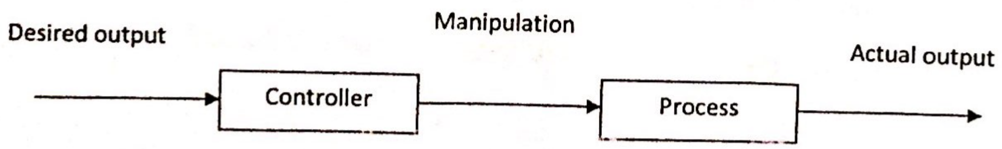
1- Open-loop control system.   2- Closed-loop control system.

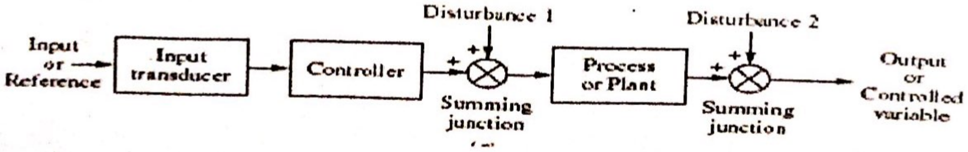
In open-loop system the control action is independent of output. In closed-loop system control action is somehow dependent on output.

Open-Loop Control (no feedback)

Open-loop control system is used for very simple applications where inputs are known ahead of time and there is no disturbance. Here the output is sensitive to the changes in disturbance inputs. Disturbance inputs are undesirable inputs that tend to deflect the plant outputs from their desired values. They must be calibrated and adjusted at regular intervals to ensure proper operation.

An open-loop control system utilizes an actuating device to control the process directly without using feedback.





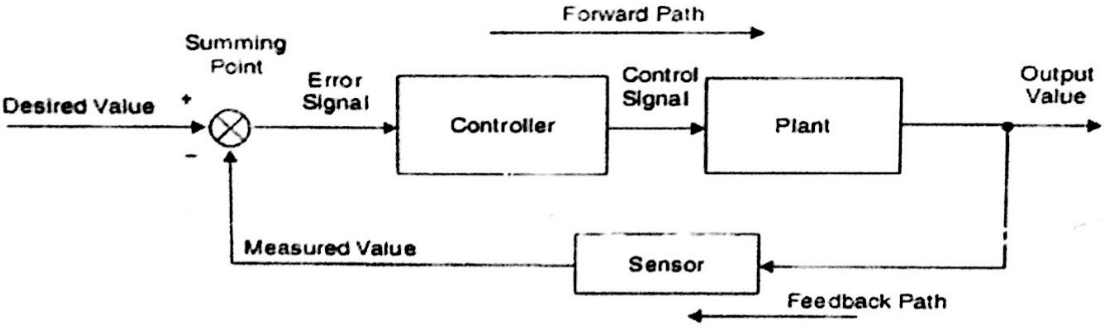
Single-Input, Single-Output Process (SISO)

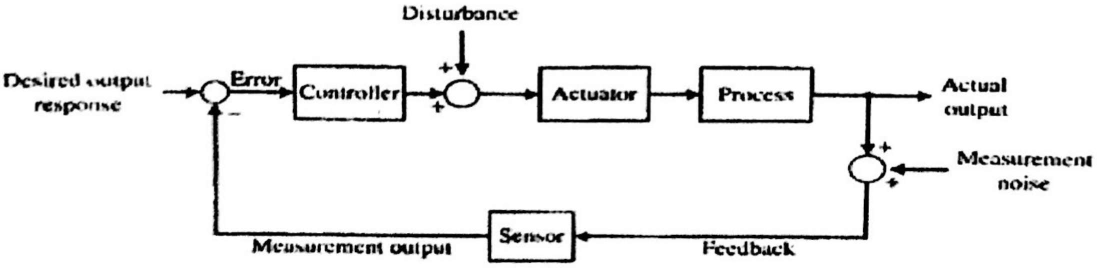
Closed-Loop Control (feedback)

Closed-loop systems are also called feedback control systems. Feedback is the property of the closed-loop systems which permits the output to be compared with the input of the system so that appropriate control action may be formed as a function of inputs and outputs.

The important features of closed-loop control systems are:

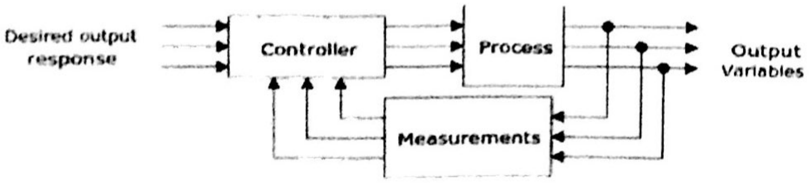
- reduced effect of nonlinearities and distortion
- Increased accuracy.
- Reduced sensitivity due to external disturbances and internal variations in system parameters.
- Increased bandwidth. The bandwidth of a system is the range of frequencies of the input over which the system will respond satisfactorily.





Note that the above system has one input and one output. [SISO]

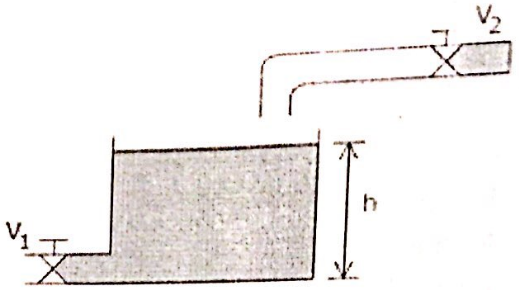
As the complexity of the systems under control increases, the interrelationship of many controlled variables must be considered in the control scheme. In this case we have a multivariable control system. [MIMO]



Example of an open-loop control system

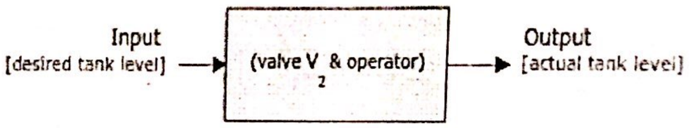
Simple tank level control system

- We wish to hold the tank level, h, within reasonable acceptable limits even though the outlet flow through valve V1 is varied. This can be achieved by irregular manual adjustment of the inlet flow rate by valve V2.



- This is not a precision system since it does not have the capability of, the input flow rate through valve V2 accurately measuring the output flow rate through V1 , or the tank level.

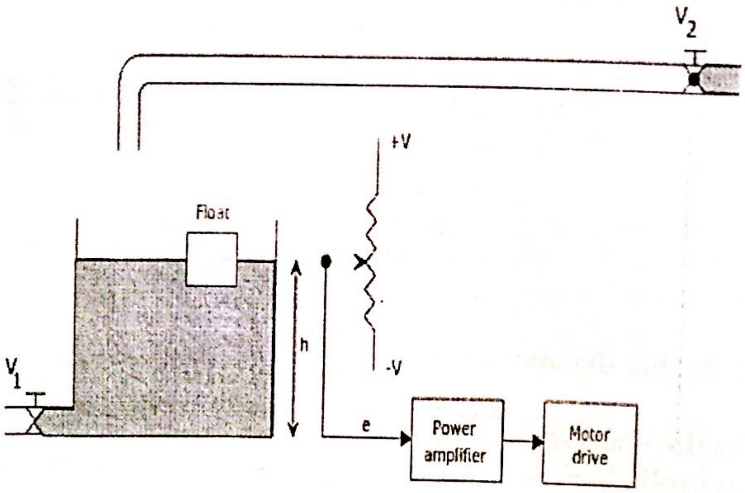
The simple relationship between the input (the desired tank level) and the output (the actual tank level) can be represented by a block diagram



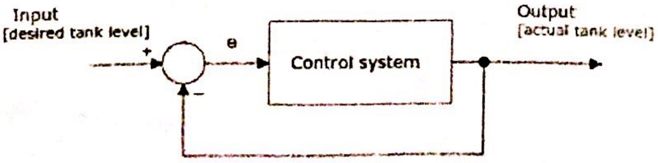
Example of a closed-loop control system

Automatic tank level control system

The above figure illustrates an automatic tank level control system. It can maintain the desired tank level **h** within quite accurate tolerances even though the output flow rate through valve V1 is varied. If the tank level is not correct, an error voltage, **e** is developed. This is amplified and applied to a motor drive which adjusts valve V2 in order to restore the desired tank level by adjusting the inlet flow rate.



A block diagram of this system is shown.



Example

For each one of the following systems, argue if in your opinion it is open–loop or closed–loop. In your argument, include your dentitions of the system's inputs and outputs. Briefly describe how feedback is effected in the systems which you decide are closed–loop.

a) Washing machine.
b) Audio speaker.
c) Air conditioner.
d) Manual gear train in an automobile.
e) Automatic gear train in an automobile.

---

a) Washing machine.

Input: switch–on; **output:** clean clothes. **Open loop.**
The washing machine does not feed back the cleanliness of clothes.

b) Audio speaker.

Input: electrical signal from readout device (e.g. laser in a CD player); **output**: microphone vibration. **Open loop.**
The output audio level and quality is not used to determine the input to the speaker.

c) Air conditioner.

Input: desired temperature; **output**: temperature. **Closed loop**.
The vast majority of air conditioners have temperature sensors (often, a simple bimetal switch) so they turn themselves on when the temperature is outside a prescribed range, off when it is inside the prescribed range.

d) Manual gear train in an automobile.

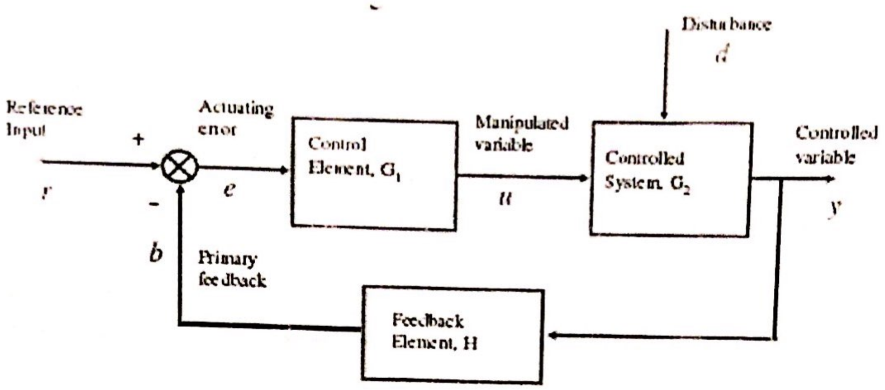
Input: lever location set by driver; **output**: wheel RPM. **Open loop**.
The wheel speed is not used in determining the gear setting (though a good driver would probably apply a sense of the vehicle's present speed to decide the proper gear to apply so as not to stall or rev up the engine.)

e) Automatic gear train in an automobile.

Unlike the manual gear-box, in the automatic gearbox (as the name implies!) there is a feedback mechanism: the wheel RPM heats up a special fluid causing it to expand or contract. The engine gear ratio is changed due to the fluid volume change.

Control System Terminology

A general (negative) feedback control system containing the basic elements is as shown in the figure below.



Definitions: ***Variables in the System***

Reference Input: r is the actual input to the system

Controlled Variable: y is the output of the controlled system

Primary Feedback: b is a function of y

Actuating Error: e is r – b

Manipulated Variable: u is the output of G1 and applied to G2

Disturbance: d is the unwanted signal that tends to affect y. d may be introduced into the system at many places

Definitions: System Components

Control Element: G1 produces u from e

Controlled System: G2 is the process or plant that is to be controlled

Feedback Element: H produces b from y

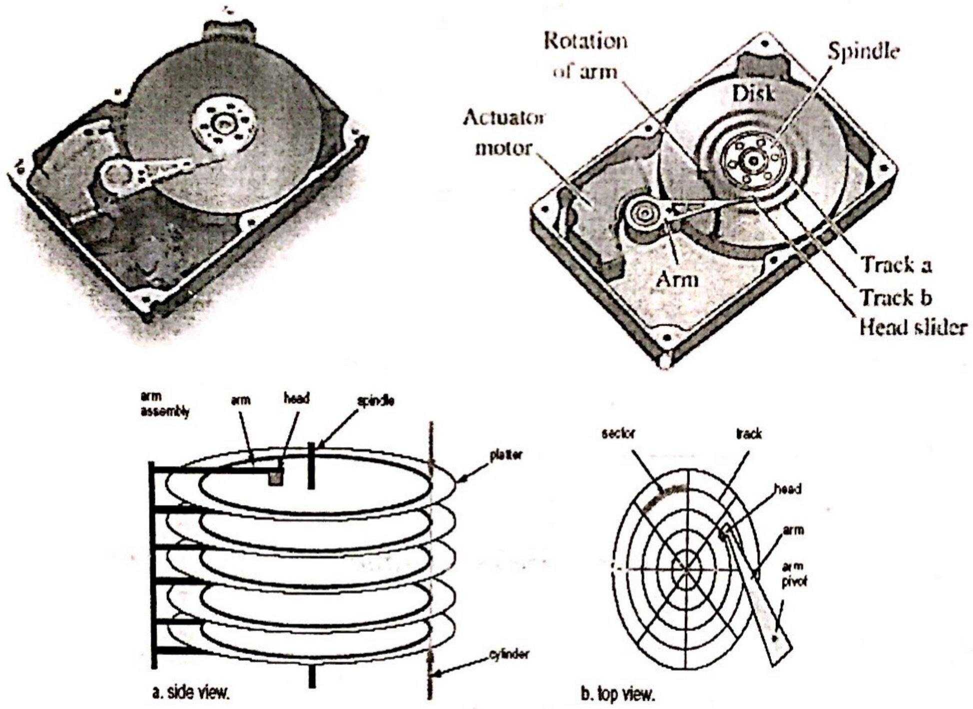
Supplementary Terminology

Forward Path: The transmission path from the actuating error **e** to the controlled variable **y**

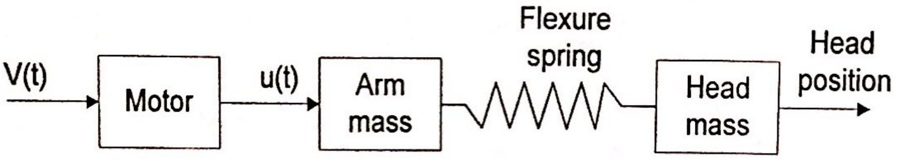
Feedback Path: The transmission path from controlled variable **y** to the primary feedback **b**

Examples of Control Systems Applications

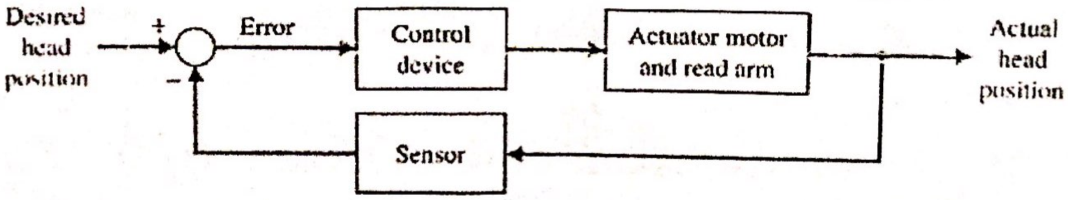
1- Disk Drive System



Disk Drive System



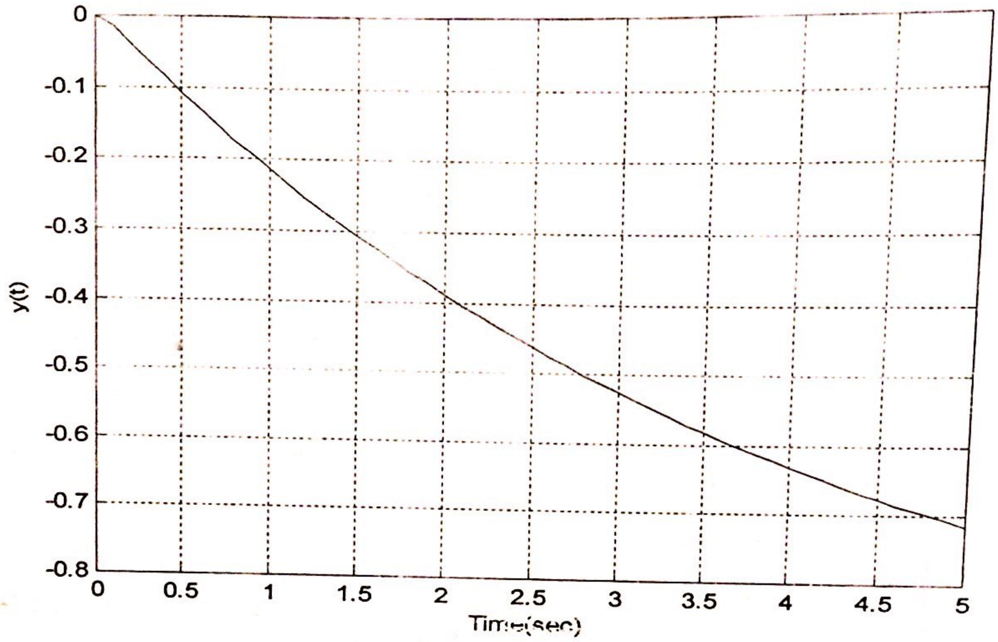
Block diagram of disk drive system (open loop system)



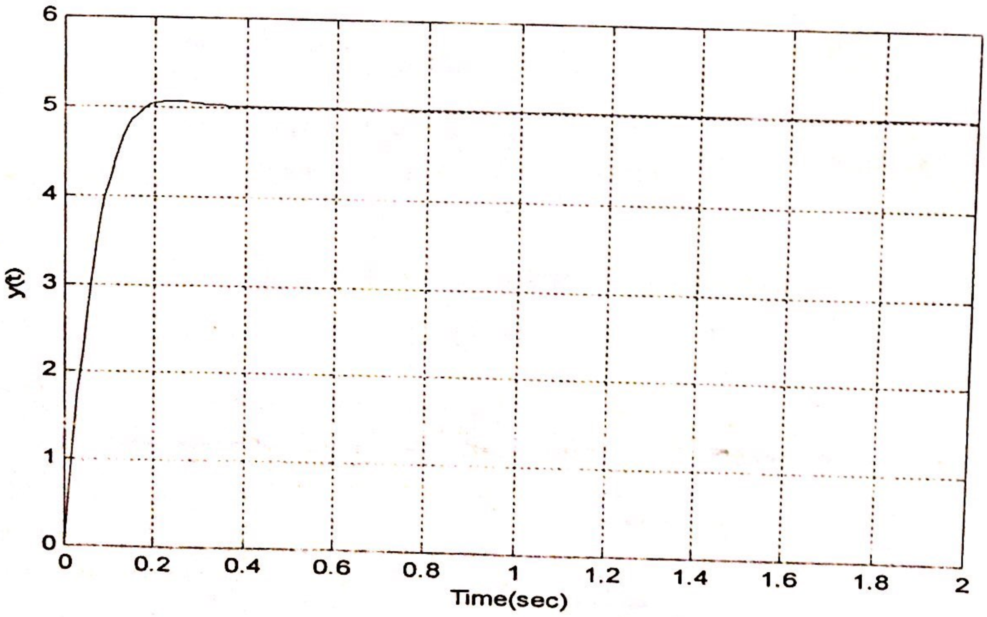
Block diagram of disk drive system (close loop system)

y(t) = Desired head position = 5

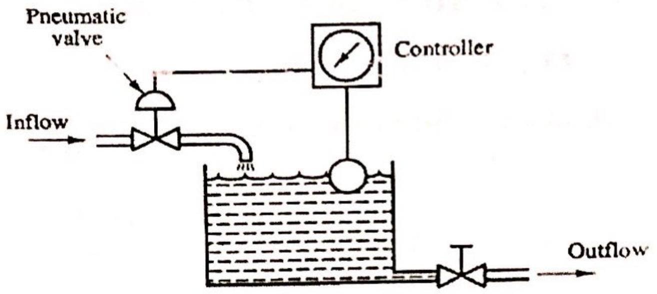
Open loop system



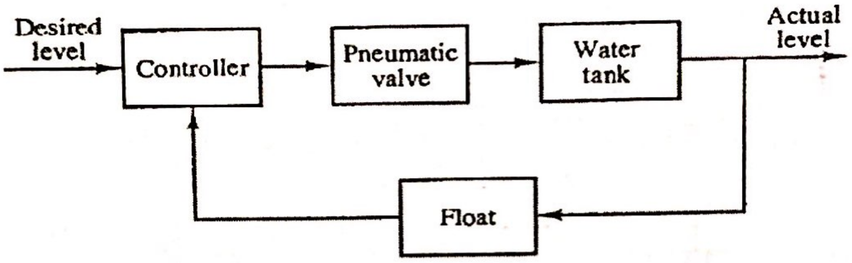
Close loop system



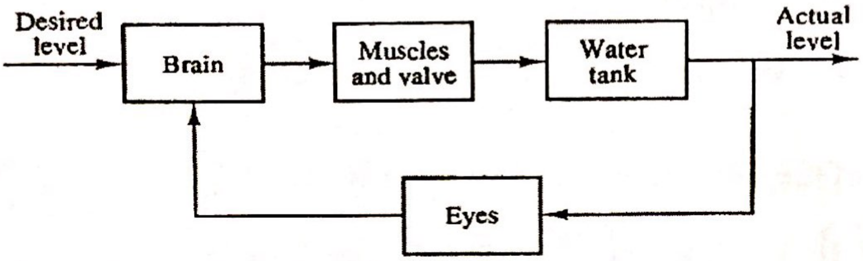
2- Liquid level control system



Liquid-level control system

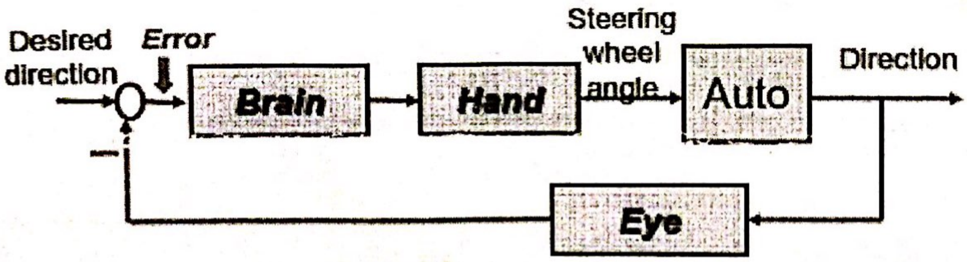


Block diagram of Liquid control system



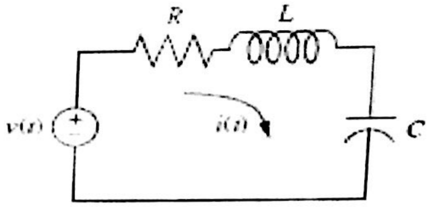
Block diagram of human operated Liquid control system

3- Automobile direction control



Block diagram of Automobile direction control

Revision to Differential equations



Q1- Given the electric network shown in Figure bellow. Assume R = 1Ω, L = 0.5H, and1/LC =30.

a. Write the differential equation for the network if v(t) =u(t), a unit step.

b. Solve the differential equation using classical method for the current, i(t) and the given initial conditions i(0)=0 , di(0)/dt =2.

c. Make a plot of your solution.

a. Writing the loop equation, $Ri + L\frac{di}{dt} + \frac{1}{C}\int i dt + v_C(0) = v(t)$

b. Differentiating and substituting values, $\frac{d^2i}{dt^2} + 2\frac{di}{dt} + 30i = 0$

Writing the characteristic equation and factoring,

$$M^2 + 2\,M + 30 = \left(M + 1 + \sqrt{29}\,i\right)\left(M + 1 - \sqrt{29}\,i\right)$$

The general form of the solution and its derivative is

$$i = e^{-t}\cos\left(\sqrt{29}\,t\right)A + \left(B\sin\left(\sqrt{29}\,t\right)\right)e^{-t}$$

$$\frac{di}{dt} = \left(-A + \sqrt{29}\,B\right)e^{-t}\cos\left(\sqrt{29}\,t\right) - \left(\sqrt{29}\,A + B\right)e^{-t}\sin\left(\sqrt{29}\,t\right)$$

Using $i(0) = 0; \frac{di}{dt}(0) = \frac{v_L(0)}{L} = \frac{1}{L} = 2$

$i\ (0) = A = 0$

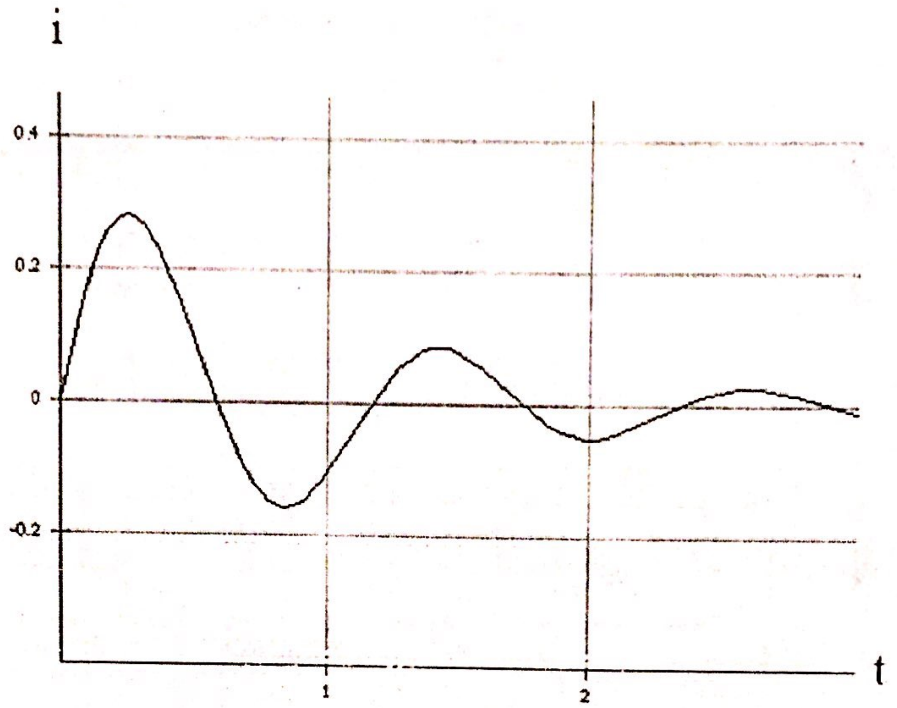
$\frac{di}{dt}(0) = -A + \sqrt{29}B = 2$

Thus, $A = 0$ and $B = \frac{2}{\sqrt{29}}$.

The solution is

$$i = \frac{2}{29}\sqrt{29}\, e^{-t}\sin\left(\sqrt{29}\, t\right)$$

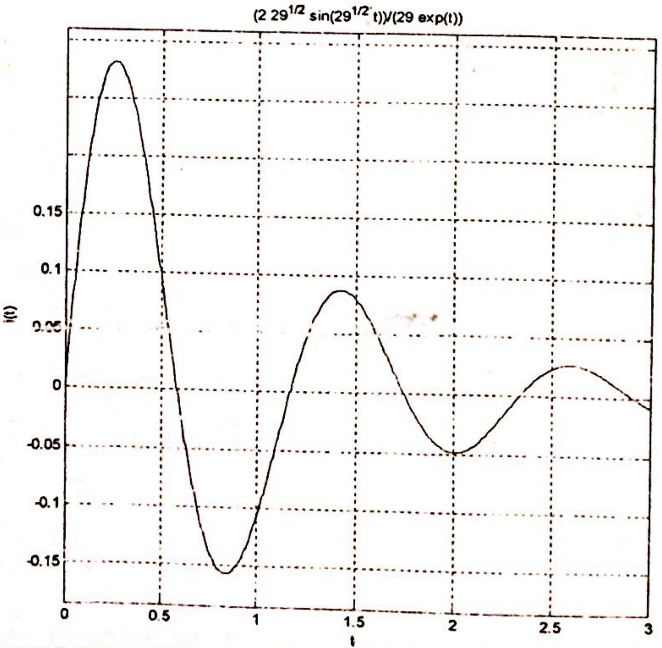
c.



MATLAB Code

```
syms, i
it= dsolve('D2i+2*Di+30*i=0','Di(0)=2','i(0)=0');
disp('i(t)=')
pretty(it)
ezplot(it,[0,3])
xlabel('t')
ylabel('i(t)')
grid
```

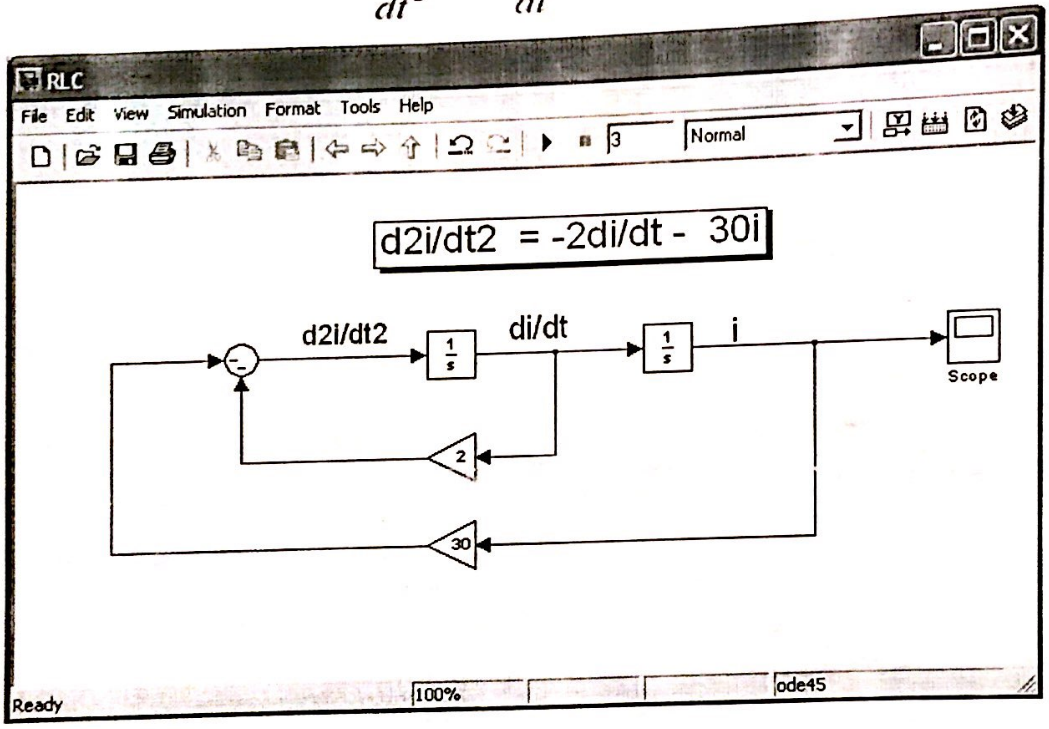
```
i(t)=

      1/2                    1/2
  2 29     exp(-t) sin(29     t)
  -----------------------------
               29
```

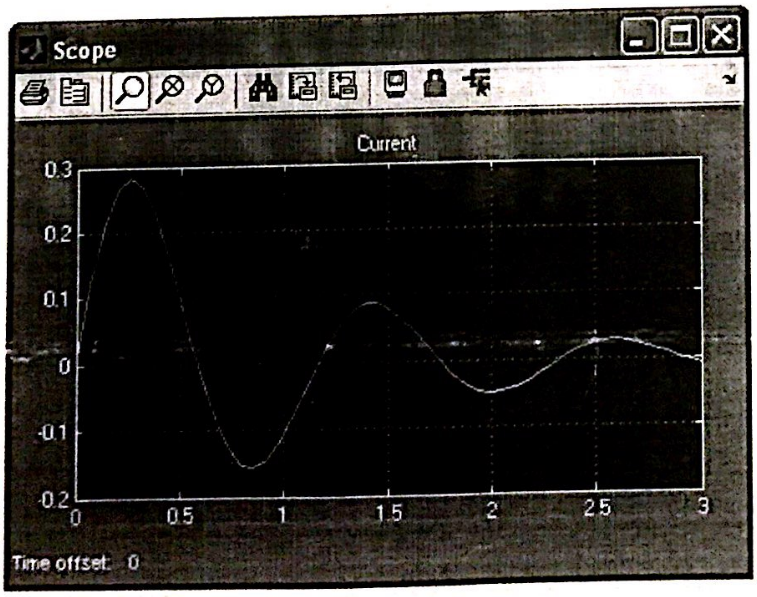


Simulink Model

$$\frac{d^2 i}{dt^2} + 2\frac{di}{dt} + 30i = 0$$

$$\frac{d^2 i}{dt^2} = -2\frac{di}{dt} - 30i$$





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Some Useful MATLAB Commands

for control system

tf , tfdata , pole , zero , pzmap , residue ,

ltiview , sisotool , series , parallel , feedback , cloop ,

zpk , ss , tf2ss , ss2tf , rlocus , rlocfind ,

bode , margin , nyquist , logspace , semilogx , step ,

lsim , eig , damp , ssdata , impulse , initial ,

laplace , ilaplace , ztrans , iztrans ,c2d , d2c ,

Other Possibly Useful Functions

solve , dsolve , roots , inv , tzero , angle ,

abs , poly , polyval , find , unwrap , linspace ,

conv , size , length , real , imag , sum ,

prod ,eval , abs , angle , compass , max ,

min ,trace , diag , complex , ones , zeros ,

fliplr , flipud

HW#1 **EE362**

1- Write a program to convert temperature in Fahrenheit degrees (±F) to centigrade degrees (±C). Use **input** and **fprintf** commands to display a mix of text and numbers. Recall the conversion formulation, $C=\frac{5}{9}(F-32)$.

2- Write a command MATALB, with two input and two output arguments that determines the height in centimeters (cm) and mass in kilograms (kg) of a person from his height in inches (in.) and weight in pounds (lb).

3- Let x = [3 2 6 8]' and y = [4 1 3 5]' (NB. x and y should be column vectors).

a. Add the sum of the elements in x to y

b. Raise each element of x to the power specified by the corresponding element in y.

c. Divide each element of y by the corresponding element in x

d. Multiply each element in x by the corresponding element in y, calling the result "z".

4- To solve the linear system of equations (do not use *solve*, use *inv* command instead).

a. x + 3y + 5z =10 X = [x,y,z معاملات مصفوفة [illegible])

b. 3x + 2z + 6y=7.5 b = [الثوابت]

c. 2.5 x+ 6y + 6z − 5 = 0 sol = inv(X)* b

5- To solve the linear system of equations (do not use *solve* fun. use ***ldivide*** command instead)

a. x + 2y + 5.5z = 9.9

b. 3x + 4z + y = 12

c. 0.5x + 4y + 6z - 10 = 0

6- Write a simple loop to list the squares of the first 10 integers.

7- Use a simple while loop, write a script to sum the series 1 + 2 + 3 + ... (so that) the sum is as large as possible without exceeding 100.

The program should display how many terms are used in the sum.

8- Type this matrix in MATALB and use it to answer the following question

i j i=1 i=5 j=5

1,5
2,4
3,3
4,2
5,1 j=5

$$A = \begin{bmatrix} 3 & 7 & -4 & 12 \\ -5 & 9 & 10 & 2 \\ 6 & 13 & 8 & 11 \\ 15 & 5 & 4 & 1 \end{bmatrix}$$

a- Create a vector v consisting of the elements in the second column of A.

b- Create a vector w consisting of the elements in the second row of A.

9- Write program to input matrix 5.5, then find :

a- sum elements of main diagonal.

b- sum elements of secondary diagonal.

c- Eigenvalue and eigenvector.

d- Max. and min. element in the matrix.

e- deviation each element from mean.

10 - The equivalent impedance of a circuit is given $Z_{eq}(j\omega) = 300 + 2j\omega L + \frac{1}{j\omega C}$

If L=4 H and C= 1 μF .write program to find $|Z(j\omega)|$ versus ω.

11- Given a function $y = x^n$.

a) Create x in the range [-1 1] with intervals of 0.05.

b) Calculate a four-column matrix, 1st column with values of x and 2nd column x^2 and 3rd column x^3 and 4th column x^4

c) Plot the 1st column versus x. Use interactive menus to change line properties.

d) Plot both first and second column versus x in dashed lines.

e) Label the x axis as x, the y axis as functions. General title is Approximation (in bold letters). Choose various fonts, sizes and colors. Add legends for the 2 curves.

12- Convert the following into quantity (Real & Imaginary) [3+2j , 5-4j , 6+7j] into (Magnitude. & Phase).

13- solve the ODE $\frac{d^3y}{dt^3} - 4\frac{d^2y}{dt^2} - \frac{dy}{dt} + 3y = \cos t$,and the initial condition

$y''(0) = 0$, $y'(0) = 0$, $y(0) = 0$ and plot the result.